

Silane-based, Cr-free passivation technology:

Superior bare corrosion protection of zinc/zinc alloy-coated steel coils

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1. General description

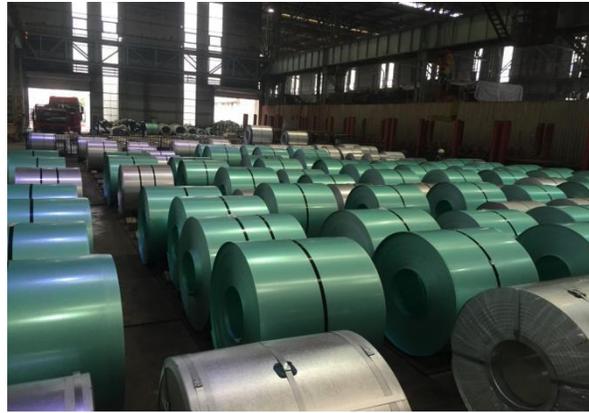
A fresh zinc-coated or galvanized steel coil surface is prone to oxidation or corrosion when exposed to humid environments during shipping and/or storage. This type of zinc corrosion is often called “wet storage stain”. Historically, toxic hexavalent chromium (Cr6)-based passivation solution is applied onto a fresh zinc-coated steel coil surface to form an anticorrosive thin layer (conversion coating). To date, environmentally friendly alternatives have been developed and are in use in the steel coil industry. The most successful alternative technologies include:

- **Silane-based, Cr-free passivation**
- Trivalent Chromium (Cr3) passivation
- Cr-free Thin Organic Coatings (TOCs)

Figure 1 shows the galvanized steel sheet being treated by an aqueous silane-based passivation solution by using the roll coating method on a continuous galvanizing line (CGL) and the produced GI coils.



(a)



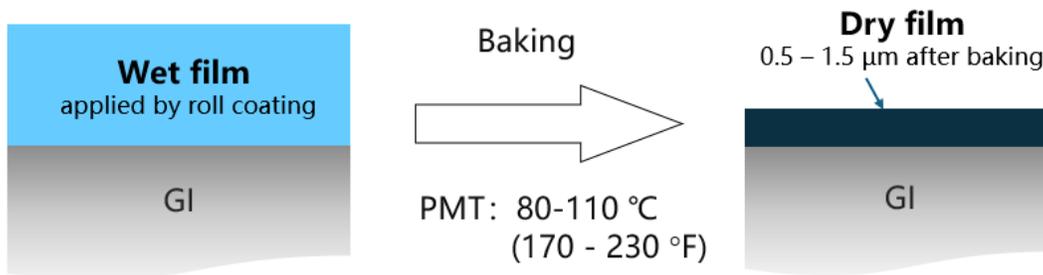
(b)

Figure 1. (a) freshly galvanized steel sheet (GI) being treated with a silane-based passivation solution by roll coating equipment and (b) passivated GI coils in different color versions (green colored and colorless)

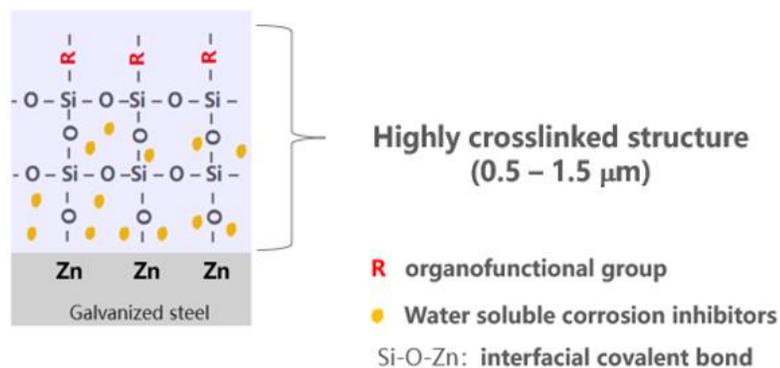
2. Silane-based, Cr-free passivation technology

2.1 Mechanism

This Cr-free passivation technology is based on organo-functional trialkoxysilane chemistry. The generic formula consists of hydrolyzed trialkoxysilanes, resins and soluble corrosion inhibitors. These products are slightly acidic emulsions (pH 4.0 -5.5) with a solid content of 15%, and can be applied onto a GI surface by roll coating/spray/immersion. On CGL, a forced baking step follows the roll coating step to quickly drive water and other solvents out of the wet passivation layer as shown in Figure 2. A dry passivation film between 0.5 – 1.5 μm thick forms on the metal surface. This adherent thin film has a highly crosslinked structure to offer excellent corrosion resistance for GI.



(a)



(b)

Figure 2. The formation of a silane-based, Cr-free thin passivation film on GI; (a) 2-step process for passivation film formation and (b) the structure of a dry passivation film

There are 3 key reactions occurring during the baking step shown in Figure 2(a):

- 1) Hydrolyzed trialkoxysilane molecules react among themselves to form a dense network structure (Si-O-Si). This network is highly water resistant.
- 2) Hydrolyzed trialkoxysilane molecules react with the zinc oxide layer on GI to form covalent bonds (Si-O-Zn). A high density of Si-O-Zn covalent bonds ensures the passivation anchors tightly to the GI surface.
- 3) Organic resin particles fuse to form a continuous film (blue in Figure 2(b)) mixed with siloxane (Si-O-Si) lattice network. This adds additional properties such as flexibility and fingerprint resistance to the passivation film.

2.2. Products and lab test results

A series of silane-based, Cr-free passivation products developed have successfully been used for zinc/zinc alloy coated steel, such as GI and Zn-Al-Mg.

2.2.1. Silane-based, Cr-free passivation products for GI

XCF-100: an aqueous silane-based Cr-free passivation product (pH 4.0-6.0, ~13% solids). Very good corrosion resistance, RoHS compliant, compatible with various paints.

Table 1. Test results for XCF-100 passivated GI

Test items		Test result (film thickness: 0.7 µm)
Corrosion resistance (Salt spray test)	Flat area	No rust after 72 h
	"X" scribed area	No rust, no delamination after 48 h
	6-mm cupping dome area	No rust after 48h
Heat resistance (240°C*20min)		No yellowing
Humidity resistance (50°C/95%Rh/120h)		No rust
Surface conductivity		0.05 mΩ
Solvent resistance (MEK and 80% ethanol, 20x double rubs)		No changes in appearance
Paint adhesion		Crosshatch: no delamination
		Impact: no cracking

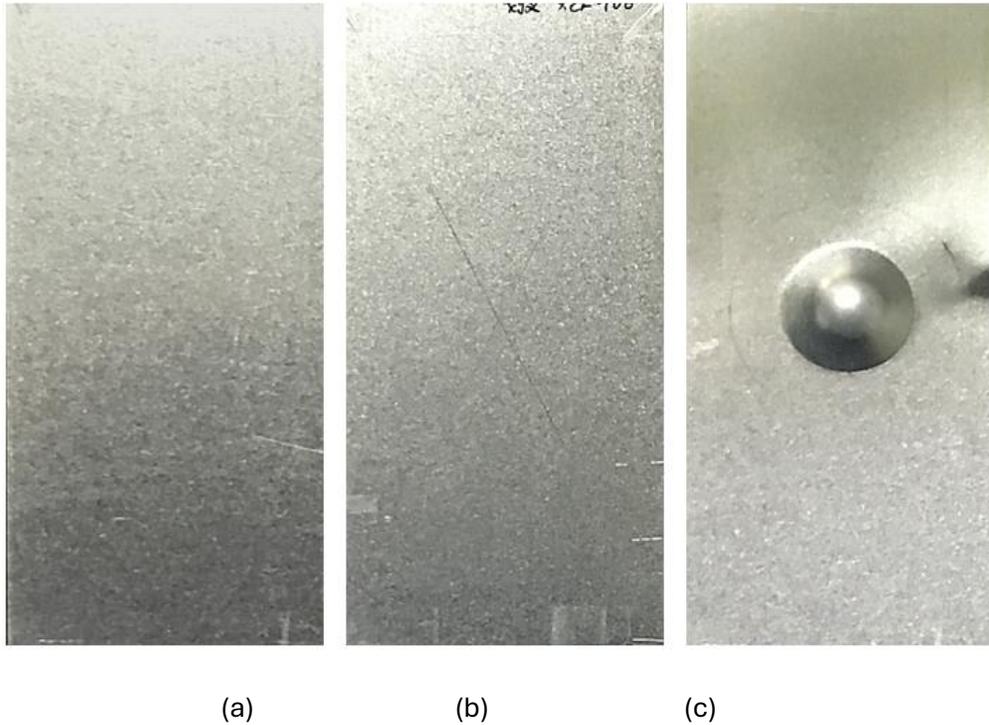


Figure 3. SST results for XCF-100 passivated GI; (a) Flat area (no rust, 72h), (b) “X” scribed area (no rust and delamination, 48 h) and (c) 6-mm cupping dome area (no rust, 48 h)

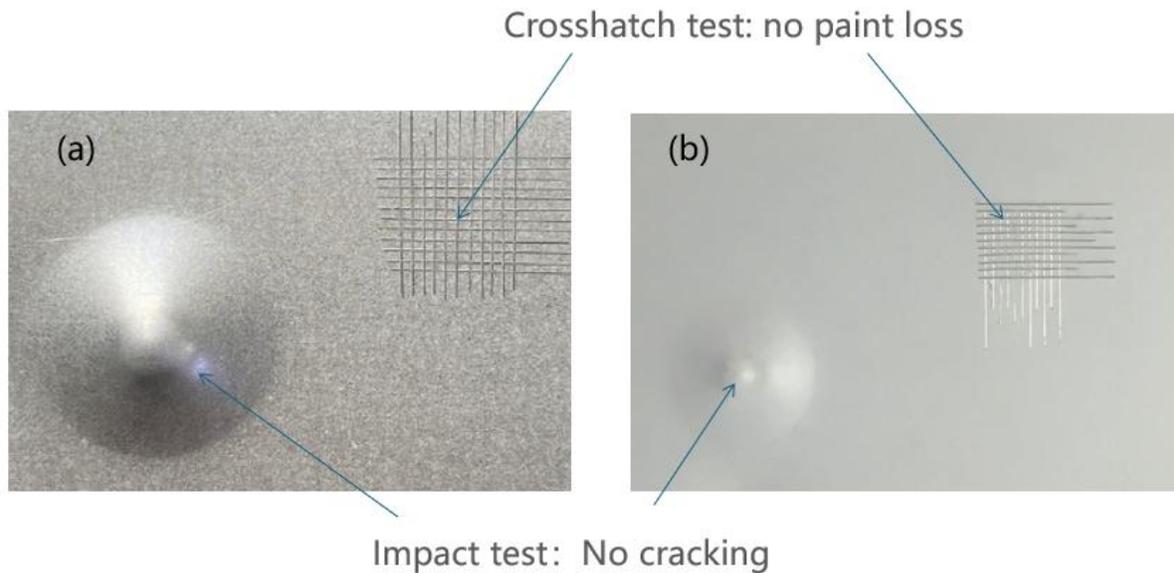


Figure 4. Paint adhesion test results for XCF-100 passivated GI; (a) top-coated with solvent-borne clear alkyd paint (25µm) and (b) top-coated with polyester powder coat (60-80µm)

XAF-200: a silane-based, Cr-free anti-fingerprint solution (pH 4.0-6.0, ~15% solids), excellent corrosion resistance and fingerprint resistance, effectively prevents sweat stains or fingerprint residue, good formability, compliant with RoHS and REACH standards

Table 2. Test results for XAF-200 passivated GI

Test items		Test result (film thickness: 1.0 μm)
Corrosion resistance (Salt spray test)	Flat area	No rust after 72 h
	"X" scribed area	No rust, no delamination after 48 h
	6-mm cupping dome area	No rust after 48h
Heat resistance (240°C*20min)		No yellowing
Humidity resistance (50°C/95%Rh/120h)		No rust
Surface conductivity		0.08 mΩ
Solvent resistance (MEK and 80% ethanol, 20x double rubs)		No changes in appearance
Anti-fingerprint (Vaseline wipe on and keep for 20 min, and wipe off)		No stain

XSL-100: Silane-based self-lubricating solution (pH 4.0-6.0, ~18% solids). This product imparts excellent formability to GI sheets. During the stamping process, the XSL-100 film provides good ductility that protects the processed GI surface from being damaged. XSL-100 passivated GI has excellent corrosion resistance, complying to RoHS and REACH standards.

Figure 5 compares the self-lubrication (XSL-100) process with the conventional passivation process. The advantages of using self-lubrication product XSL-100 are clearly demonstrated: 1) reduced wastewater management cost by eliminating degreasing and rinse steps and 2) overall cost saving by simplifying the entire process

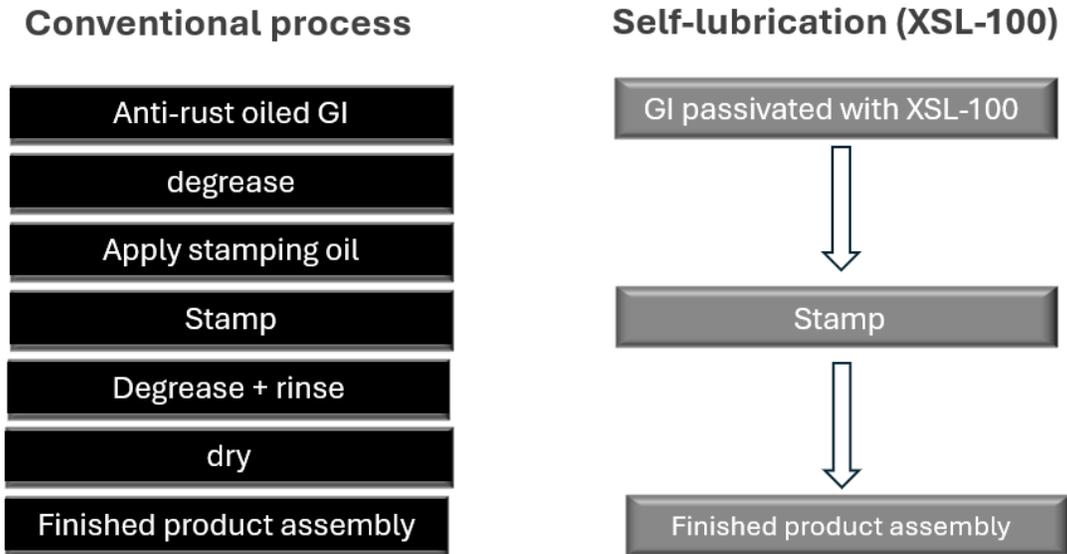


Figure 5. conventional process vs. simplified process by using XSL-100

Table 3. The test results for GI sheets passivated with XSL-100

Test items		Test result (coating thickness: 1.0µm)
Corrosion resistance (Salt spray test)	Flat area	No rust after 96 h
	6-mm cupping dome area	No rust after 48 h
Heat resistance (240°C*20min)		No yellowing
Humidity resistance (50°C/95%Rh/120h)		No rust, no blackening
Solvent resistance (MEK and 80% ethanol, 20x double rubs)		No changes in appearance
Forming/stamping properties		the stamped area do not turn black or crack
ductility		the stamped area do not turn black or crack
Coefficient of friction		0.081

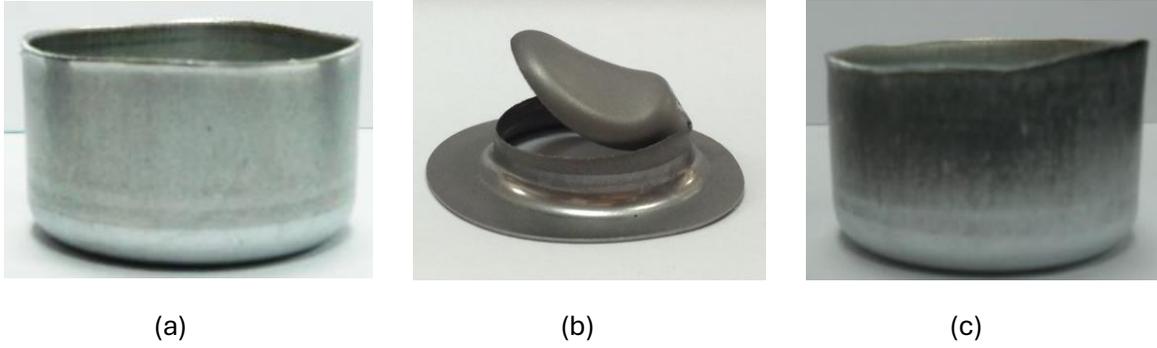


Figure 6. Deep drawing test results for GI with different passivation products; (a) XSL-100 (zinc coating retains its original appearance), (b) XCF-100 (cracked) and (c) XAF-100 (zinc coating severely damaged/blackened)



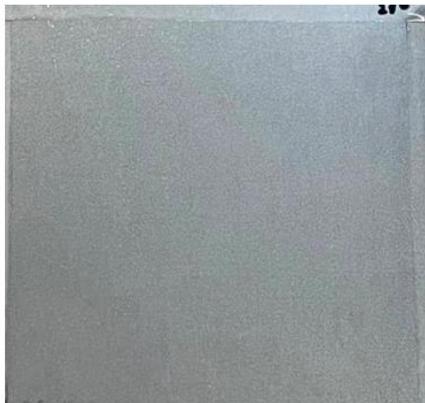
Figure 7. 40-inch color TV LCD screen frames made of XSL-100 passivated GI sheets (XSL-100 layer on GI enables the elimination of stamping oil and subsequent degreasing and rinsing).

2.2.2. Silane-based, Cr-free passivation products for Zn-Al-Mg

XAF-230: Aqueous silane-based emulsion (pH 4.0-6.0, ~15% solids). Excellent corrosion resistance and paint adhesion, good blackening resistance, RoHS compliant

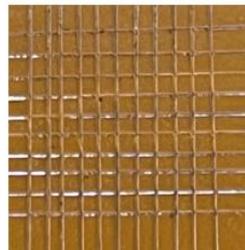
Table 4. The test results for Zn-6Al-3Mg passivated with XAF-230

Test items	Test result (film thickness: 1.0µm)
Corrosion resistance (Salt spray test)	No rust after 96 h
Heat resistance (240°C*20min)	No yellowing
Humidity resistance (50°C/95%Rh/120h)	No rust but with blackened appearance
Solvent resistance (MEK and 80% ethanol, 20x double rubs)	No changes in appearance
Paint adhesion (powder coat)	Crosshatch: no delamination
	Impact: no cracking



SST (96-h) : no rust

Paint adhesion



Cross-hatch: 5B



Impact: no crack

Powder coat: Akzo polyester powder coat
Powder coat thickness: 60-80µm

Figure 8. performance test results for Zn-6Al-3Mg passivated with XAF-230